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DESIGN STRESS ANALYSIS AND PERFORMANCE CHARACTERISTICS FOR 140-FOOT DIAMETER RSR RIBCO (RAPID INFLATION BOWLINE CONTROLLED OPENING) PARACHUTE SYSTEM

Joe A. Haden

Recovery Systems Research, Incorporated

Prepared for:

Air Force Cambridge Research Laboratories

30 July 1972

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Recovery Systems Research, Inc.
P. O. Box 137
Alamogordo, New Mexico 88310

Contract No. F19628-72-C-0131
Project No. 9698
Task No. 969800
Work Unit No. 96980001

FINAL REPORT

Period Covered
2 December 1971
to
1 April 1972

Date of Report
30 July 1972

This research was supported by the National Aeronautics and Space Administration under NASA DPR #L-9698.

Contractor Monitor: James C. Payne
Aerospace Instrumentation Laboratory

Prepared
for
AIR FORCE CAMBRIDGE RESEARCH LABORATORIES
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
BEDFORD, MASSACHUSETTS 01730

25

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UNCLASSIFIED

Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)* Recovery Systems Research, Inc. P.O. Box 137 Alamogordo, New Mexico 88310	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE
Design Stress Analysis and Performance Characteristics for 140-Ft Diameter RSR RIBCO Parachute System

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*
Scientific Final 2 December 1971 - 1 April 1972 Approved 18 Oct 72

5. AUTHOR(S) *(First name, middle initial, last name)*
Joe A. Haden

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
30 July 1972	30	5

8a. CONTRACT OR GRANT NO. NASA DPR #L-9698 F19628-72-C-0131 b. PROJECT, TASK, WORK UNIT NOS. 9698-00-01 c. DOD ELEMENT 000000 d. DOD SUBELEMENT 63920E	9a. ORIGINATOR'S REPORT NUMBER(S) 9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)* AFCRL-72-0451

10. DISTRIBUTION STATEMENT
A - Approved for public release; distribution unlimited

11. SUPPLEMENTARY NOTES This research was supported by the National Aeronautics and Space Administration	12. SPONSORING MILITARY ACTIVITY Air Force Cambridge Research Laboratory (LC) L.G. Hanscom Field Bedford, Massachusetts 01730

13. ABSTRACT This report presents the design, stress analysis and high altitude performance of the RSR RIBCO Parachute System. A 140-Ft diameter parachute system was tested by Air Force Cambridge Research Laboratories. This system was released from a balloon at 100,000 ft altitude with a payload of 611 pounds. Performance characteristics (opening time, opening shock, snatch force, rate of descent and total descent time) were very nearly as predicted. Test results indicate that the RIBCO System offers many advantages over conventional parachute systems.

14. Key Words
- Multi Purpose
- High Altitude
- Rapid Inflation
- Lightweight
- Controlled Opening
- Minimum Snatch Force
- Minimum Opening Shock
- No Ancillary Reefing
- Heavy Payload
- Fast Opening

AFCRL-72-0451

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II

ABSTRACT

This report presents the design, stress analysis and high altitude performance of the RSR RIBCO Parachute System. A 140-foot diameter parachute system was tested by Air Force Cambridge Research Laboratories. This system was released from a balloon at 100,000 feet altitude with a payload of 611 pounds.

Performance characteristics (opening time, opening shock, snatch force, rate of descent and total descent time) were very nearly as predicted. Test results indicate that the RIBCO System offers many advantages over conventional parachute systems.

INTRODUCTION

Recovery Systems Research, Inc. has developed a parachute recovery system through a series of 40 test drops with parachutes ranging from 28-ft nominal diameter to 140-ft nominal diameter and recovered loads of 300 pounds to 5800 pounds. The purpose of this development effort was to produce a multi-purpose parachute system (utilizing one parachute) with optimum performance characteristics both at extremely high and low altitudes with heavy and light loads and without deployment aids such as time delay reefing and forced deployment mortars.

Testing has not been pursued to the extent that the RSR RIBCO (Rapid Inflation Bowline Controlled Opening) parachute system is operational for balloon payload recovery; however, it appears to be a substantial improvement over the presently used parachute systems.

The RIBCO parachute system design permits the use of one standard size parachute for recovery of minimum and maximum payloads since the unique rigging insures inflation at any velocity. This rigging also limits the opening dynamics to such an extent that very light canopy material can be used in construction thus permitting fabrication of larger parachutes with higher load carrying capability and eliminating the need for reefing to control parachute opening.

One high altitude balloon payload recovery test has been made by AFCRL utilizing the 140-ft RIBCO parachute system. The 611-pound payload for this test approached the minimum, 500 pounds, for which the parachute system was designed. Optimum performance is expected when the parachute system is utilized with maximum rated load of 8,000 pounds.

Reference AFCRL Preliminary Report on AFCRL Flight 72-26 Proceedings, Seventh AFCRL Scientific Balloon Symposium.

DESIGN STRESS ANALYSIS AND PERFORMANCE
CHARACTERISTICS FOR 140-FOOT DIAMETER RIBCO PARACHUTE

V

LIST OF MATERIALS

ITEM	RATED TENSILE STRENGTH
Fabric - 1.1 oz/yd	40 lbf/in
Control Lines	6000 lbf
Suspension Lines	550 lbf
Apex Lines	750 lbf
Radial Tapes	250 lbf
Apex Loop Line	10,000 lbf

DESIGN DATA

Symbol	Meaning	Units
D_o	Nominal Diameter	140 ft
S_o	Total Area	15,394 ft^2
S_f	Frontal Area	10,776 ft^2
Z_s	Number of Suspension Lines	120
Z_c	Number of Control Lines (Bowline)	12
R_p	Canopy Radius	58.57 ft
ρ_{sl}	Sea Level Atmospheric Density	$\frac{.002377 \text{ lb-sec}^2}{\text{ft}^4}$
P_{all}	Allowable Force	lbf
P_{dev}	Developed Force	lbf
F_{max}	Maximum Developed Force	lbf
F_d	$1/2 \times F_{max}$	lbf
V	Velocity	ft/sec
V_t	Terminal Velocity	ft/sec
C_{do}	Drag Coefficient	1.05
W	Descent Weight	lb
M.S.	Margin of Safety	

Design data in this report are based upon the results of several test programs. It has been established that, with a canopy loading of 0.53 lbf/ft^2, the drag coefficient of 1.05 is experienced.

Accordingly for a payload weight of 8000 lbs. and a parachute weight of 183 lbs., sea level terminal velocity will be:

$$V_t^2 = \frac{2W}{\rho C_{do} S_o}$$

$$W = 8000 + 183 = 8183 \text{ lbs}$$

$$V_t = \sqrt{\frac{2(8183) \times 10^4}{23.77(1.05)\ 15{,}394}} = \sqrt{425.95}$$

$$V_t = 20.64 \text{ ft/sec at sea level}$$

Due to the zero velocity drop condition an opening shock factor of 1.5 is assumed.

$$F_{max} = 1.5 \times 8000 = 12{,}000 \text{ lbf}$$

For a payload of 611 pounds sea level terminal velocity will be:

$$V_t = \sqrt{\frac{2 \times (611 + 183)}{.002377 \times 1.0 \times 15{,}394}} = \sqrt{\frac{1588}{36.59}} = \sqrt{43.4}$$

$$V_t = 6.6 \text{ ft/sec}$$

And at 5000 ft MSL terminal velocity will be:

$$V_t = \sqrt{\frac{1588}{2.10 \times 15{,}394}} = \sqrt{\frac{1588}{32.33}} = \sqrt{49.1}$$

$$V_t = 7.0 \text{ ft/sec}$$

The maximum force developed is assumed to be transmitted equally between the vent and skirt due to the geometrical relationship existing during the period of highest loading.

$$F_d = \frac{F_{max}}{2} = \frac{12{,}000}{2} = 6000 \text{ lbf}$$

SUSPENSION LINES (550 lbf Rated Strength)

$$P_{dev} = \frac{F_d}{Z_s} = \frac{6000}{120} = 50.0 \text{ lbf}$$

Using a design factor of 4.07 (see Table I)

$$P_{all} = \frac{550}{4.07} = 135 \text{ lbf}$$

$$M.S. = \frac{135}{50.0} - 1.00 = 2.70 - 1.00 = 1.70$$

$$M.S. = +170\%$$

LOWER CONTROL LINES (6000 lbf Rated Strength)

$$P_{dev} = \frac{Fmax}{Zc} = \frac{12000}{12} = 1000 \text{ lbf}$$

Design Factor = 2.72

$$P_{all} = \frac{6000}{2.72} = 2206 \text{ lbf}$$

$$M.S. = \frac{2206}{1000} - 1.00 = 2.21 - 1.00 = 1.21$$

$$M.S. = +121\%$$

UPPER CONTROL LINES (6000 lbf Rated Strength)

$$P_{dev} = \frac{F_d}{Z_c} = \frac{6000}{12} = 500 \text{ lbs}$$

Design Factor = 3.00

$$P_{all} = \frac{6000}{3.00} = 2000 \text{ lbf}$$

$$M.S. = \frac{2000}{500} - 1.00 = 4.00 - 1.00 = 300$$

M.S. = +300%

CONTROL LINE TO SUSPENSION LINE JUNCTION

There are ten 550 lbf test suspension lines connected to each of 12 control line junctions. The load carried by each junction, assuming symmetrical load distribution, is:

$$P_{dev} = \frac{F_d}{Z_c} = \frac{6000}{12} = 500 \text{ lbf}$$

The ultimate strength of the junction is 6000 lbf. Using the highest applicable design factor (4.07):

$$P_{all} = \frac{6000}{4.07} = 1474 \text{ lbf}$$

$$M.S. = \frac{1474}{500} - 1.00 = 2.95 - 1.00 = 1.95$$

M.S. = +195%

APEX RADIAL LINES (750 lbf Rated Strength)

Assume vent radials carry 50% of the load at the instant of opening. Sixty (60) radial lines are used.

$$P_{dev} = \frac{6000}{60} = 100 \text{ lbf}$$

Design factor = 3.70

$$P_{all} = \frac{750}{3.70} = 203 \text{ lbf}$$

$$M.S. = \frac{203}{100} - 1.00 = 2.03 - 1.00 = 1.03$$

M.S. = +103%

RADIAL TAPES (250 lbf Rated Strength)

120 Radial tapes are used

$$P_{dev} = \frac{6000}{120} = 50.0$$

Design factor = 3.00

$$P_{all} = \frac{250}{3.00} = 83.3 \text{ lbf}$$

$$M.S. = \frac{83.3}{50.0} - 1.00 = 1.66 - 1.00 = 0.66$$

M.S. = +66%

REEFED CONDITION - LIFTING

This condition exists prior to drop of the payload/canopy system. An apex loop load line, consisting of four thicknesses of 1C lbf rated strength webbing, support the system weight.

P_{dev} = 8183 lbf

Design Factor = 2.24

$$P_{all} = \frac{4(10,000)}{2.24} = 17,857 \text{ lbf}$$

$$M.S. = \frac{17,857}{8183} - 1.00 = 2.18 - 1.00 = 1.18$$

M.S. = +118%

CANOPY MAIN SEAMS

Assuming that 100% of the total maximum force is absorbed by the canopy fabric,

$$\Delta P = \frac{Fmax}{SF} = \frac{12,000}{10,776} = 1.11 \frac{lbf}{ft^2} = 0.0077 \frac{lbf}{in^2}$$

$$\text{Cloth Stress} = \Delta P \times \frac{R_p}{2} = 0.0077 \times \frac{58.57 \times 12}{2}$$

$$\text{Cloth Stress} = 2.71 \frac{lb}{in}$$

Using a design factor of 2.60 and the minimum tensile strength for 1.1 oz/yd material (40 lbf/in):

$$P_{all} = \frac{40}{2.60} = 15.4 \text{ lbf/in}$$

P_{dev} = 2.71 lbf/in

$$M.S. = \frac{15.4}{2.71} - 1.00 = 5.68 - 1.00 = 4.68$$

M.S. = +468%

CROSS SEAMS

Using a design factor of 2.92 and worst case loading:

$$P_{all} = \frac{40}{2.92} = 13.7 \ \frac{lb}{in}$$

$$P_{dev} = 1.90 \times COS\ A$$

$$P_{dev} = 1.90 \times 0.707 = 1.34 \ lb/in$$

$$M.S. = \frac{13.7}{1.34} - 1.00 = 10.22 - 1.00 = 9.22$$

M.S. = +922%

CANOPY CLOTH

Using a design factor of 3.33

$$P_{all} = \frac{40}{3.33} = 12.00 \ lb/in$$

$$P_{dev} = 1.90 \ lb/in$$

$$M.S. = \frac{12.00}{1.90} - 1.00 = 6.32 - 1.00 = 5.32$$

M.S. = +532%

HIGH ALTITUDE OPENING FORCES

Tests made at El Centro, California in 1967, demonstrated that the opening time of a 100-ft diameter RIBCO canopy is four (4) seconds when dropped from an aircraft. Assuming similar characteristics for the 140-ft diameter RIBCO/High Altitude Balloon drop, maximum opening force as a function of drop altitude can be estimated. For a 5000-lb payload with 183 lb of parachute, predicted values for maximum drag force are:

72,500 ft release: $F_{max} = 6824$ lbf

100,000 ft release: $F_{max} = 5268$ lbf

120,000 ft release: $F_{max} = 5426$ lbf

It should be noted that the stress analysis assumed $F_{max} = 12,000$ lbf with a payload of 8000 lbs.

Appendix I includes equations and computations used in arriving at the above characteristics.

STRENGTH LOSS AND SAFETY FACTORS

Symbol	Function	Canopy Cloth	Radial Lines	Suspension Lines	Control Lines Upper	Control Lines Lower	Seams Main	Seams Cross	Vent Tapes	Apex Lines
	STRENGTH LOSS FACTORS									
B	Joint Efficiency	1.00	0.90	0.90	0.90	0.90	0.90	0.80	0.90	0.90
N	Heat-Loss Factors	0.90	0.90	0.90	0.90	0.95	0.90	0.90	0.90	0.90
L	Abrasion	1.00	1.00	0.95	0.95	0.95	0.95	0.95	0.95	0.95
	SAFETY FACTORS									
J	Safety Factors	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	1.50
H	Line Convergence	NA	NA	1.25	1.05	1.05	NA	NA	1.05	1.05
F	Asymmetrical Loading	1.50	1.50	1.25	1.10	1.05	NA	NA	1.10	1.10
	DESIGN FACTORS									
Design Factor = $\frac{JHF}{BNL}$		3.33	3.70	4.07	3.00	2.72	2.60	2.92	3.00	2.24

Table I

APPENDIX I

OPENING FOR CHARACTERISTICS

For an object falling vertically through the atmosphere,

$$\Delta V = (G - \frac{D}{M})\ \Delta T, \text{ where:}$$

ΔV = The change in vertical velocity during time t
G = The acceleration due to gravity
D = Aerodynamic Drag $(1/2\ \rho\ V^2 C_d S)$
M = W/G

If the canopy is assumed to inflate linearly from a frontal diameter of 3.0 ft to that of 117.1 ft over a period of four seconds, commencing at the time of release* then the drag forces can be computed and values of vertical velocity, $V = V_o + V$, can be determined using the progressive calculation method with small time increments by varying atmospheric density with changes in altitude. Altitude is computed by: $H = (H_o - V\ \Delta T)$ for each increment. Aerodynamic drag of the payload has been neglected, and gravitational acceleration has been assumed constant as has the drag coefficient.

*It is further assumed that the systems initial velocity relative to the surrounding atmosphere will be zero.

The time of maximum drag force occurs at 4.0 seconds for the 72,500 ft. drop, 10.4 seconds for the 100,000 ft. drop, and 18 seconds for the 120,000 ft. drop. This is due to the low atmospheric densities at the higher altitudes, which allow the payload/canopy system to accelerate even after full opening, until the parachute drag increases to a force equal to the system's weight, after which the terminal (equilibrium) descent phase begins.

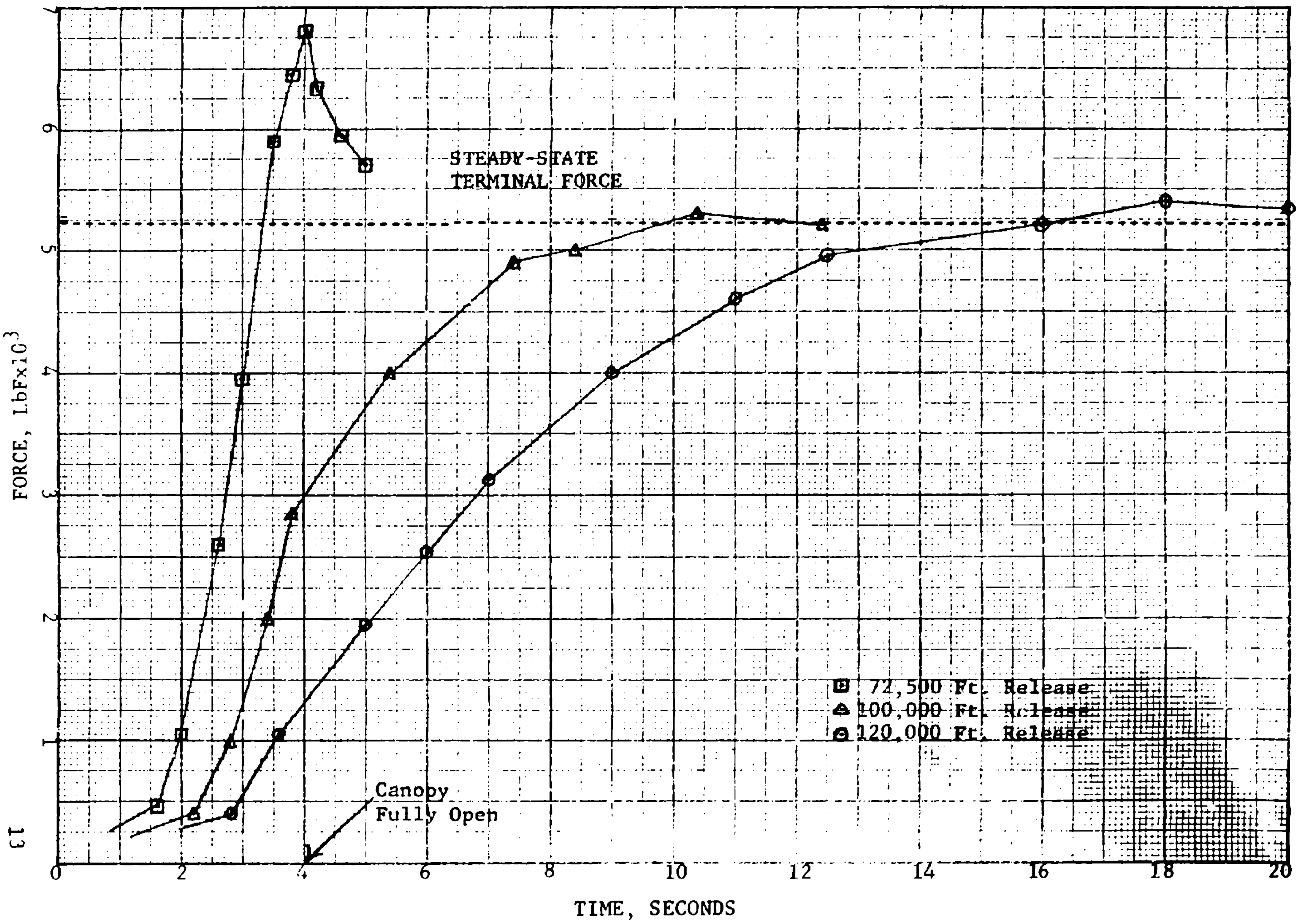
Sea level terminal velocity for the 5000-lb payload should be:

$$V_t = \sqrt{\frac{2(5183) \times 10^4}{23.77(.95)15,394}} = \sqrt{298.19}$$

$$V_t = 17.27 \text{ ft/sec}$$

The drag coefficient used in computing terminal velocity for the 5000-lb payload is approximately 10% lower than that used for the 8000-lb payload, due to lower canopy loading.

DECELERATION FORCE VS. TIME



T	C_DS	V	$V^2 \times 10^{-4}$	$\frac{\rho}{2} \times 10^{-4}$	q PSF	D Lbf	$\frac{W-D}{M}$	$\frac{W-D}{M}\Delta T$	ΔT	$\Sigma\Delta H$
0.0	10.6	0	0	.1659	0	0	32.19	6.44	0.2	0
0.2	89.4	6.44	.00415	.1659	.00688	.062	32.19	6.44	0.2	1.29
0.4	244.5	12.88	.0166	.1659	.00275	.67	32.18	6.44	0.2	3.87
0.6	492.0	19.32	.0373	.1659	.00619	3.04	32.17	6.43	0.2	7.73
0.8	785.0	25.75	.0663	.1659	.0110	8.64	32.14	6.43	0.2	12.88
1.0	1098.0	32.18	.1036	.1659	.0172	18.9	32.07	6.41	0.2	19.32
1.2	1636.0	38.59	.1489	.1659	.0147	40.4	31.94	6.39	0.2	27.04
1.4	2168.0	44.98	.2023	.1659	.0336	72.8	31.74	6.35	0.2	36.04
1.6	2793.0	51.33	.2635	.1659	.0437	122	31.43	6.29	0.2	46.3
1.8	3495.0	57.62	.3320	.1659	.0551	193	30.99	6.20	0.2	57.8
2.0	4245.0	63.82	.4073	.1659	.0676	287	30.41	6.08	0.2	70.6
2.2	5093.0	69.90	.4886	.1659	.0811	413	29.63	5.93	0.2	84.6
2.4	6083.0	75.83	.5750	.1659	.0954	580	28.59	5.72	0.2	100.0
2.6	7035.0	81.55	.6650	.1659	.1103	776	27.37	5.47	0.2	116.3
2.8	8100.0	87.02	.7572	.1659	.1256	1017	25.88	5.18	0.2	133.7
3.0	9255.0	92.20	.8501	.1659	.1410	1305	24.09	4.82	0.2	152.1
3.2	10500.0	97.02	.9413	.1659	.1562	1640	22.01	4.40	0.2	171.5
3.4	11783.0	101.4	1.028	.1659	.1705	2007	19.72	3.94	0.2	191.8
3.6	13170.0	105.3	1.109	.1659	.1840	2423	17.14	3.43	0.2	212.9
3.8	14683.0	108.7	1.182	.1659	.1961	2880	14.30	2.86	0.2	234.6
4.0	16164.0	111.6	1.245	.1659	.2065	3338	11.46	2.29	0.2	256.9
4.2	16164.0	113.9	1.297	.1659	.2152	3478	10.59	2.12	0.2	297.7
4.4	16164.0	116.0	1.346	.1659	.2233	3609	9.78	1.96	0.2	302.9
4.9	16164.0	118.0	1.392	.1659	.2309	3732	9.01	4.51	0.5	361.9
5.4	16164.0	122.5	1.501	.1659	.2497	4036	7.12	3.56	0.5	423.2
6.4	16164.0	126.1	1.590	.1659	.2638	4264	5.70	5.70	1.0	549.3
7.4	16164.0	133.8	1.790	.1698	.3039	4912	1.68	1.68	1.0	683.1
8.4	16164.0	135.5	1.836	.1698	.3118	5040	.89	.89	1.0	818.6
9.4	16164.0	136.4	1.860	.1698	.3158	5168	.48	.48	1.0	955.0
10.4	16164.0	136.9	1.874	.1739	.3259	5268	-.53	-.53	1.0	1091.0

$W_P = 5000$ Lb $H_o = 100{,}000$ ft MSL

$W_{Tot} = 5183$ Lb $V_o = 0$ Max $G = \frac{5268}{5183} \cong 1.02G$

$M = \frac{5183}{32.2} \cong 161$ $\rho_o = 0.3318 \times 10^4$

Sample calculations for descents from 100,000 ft.

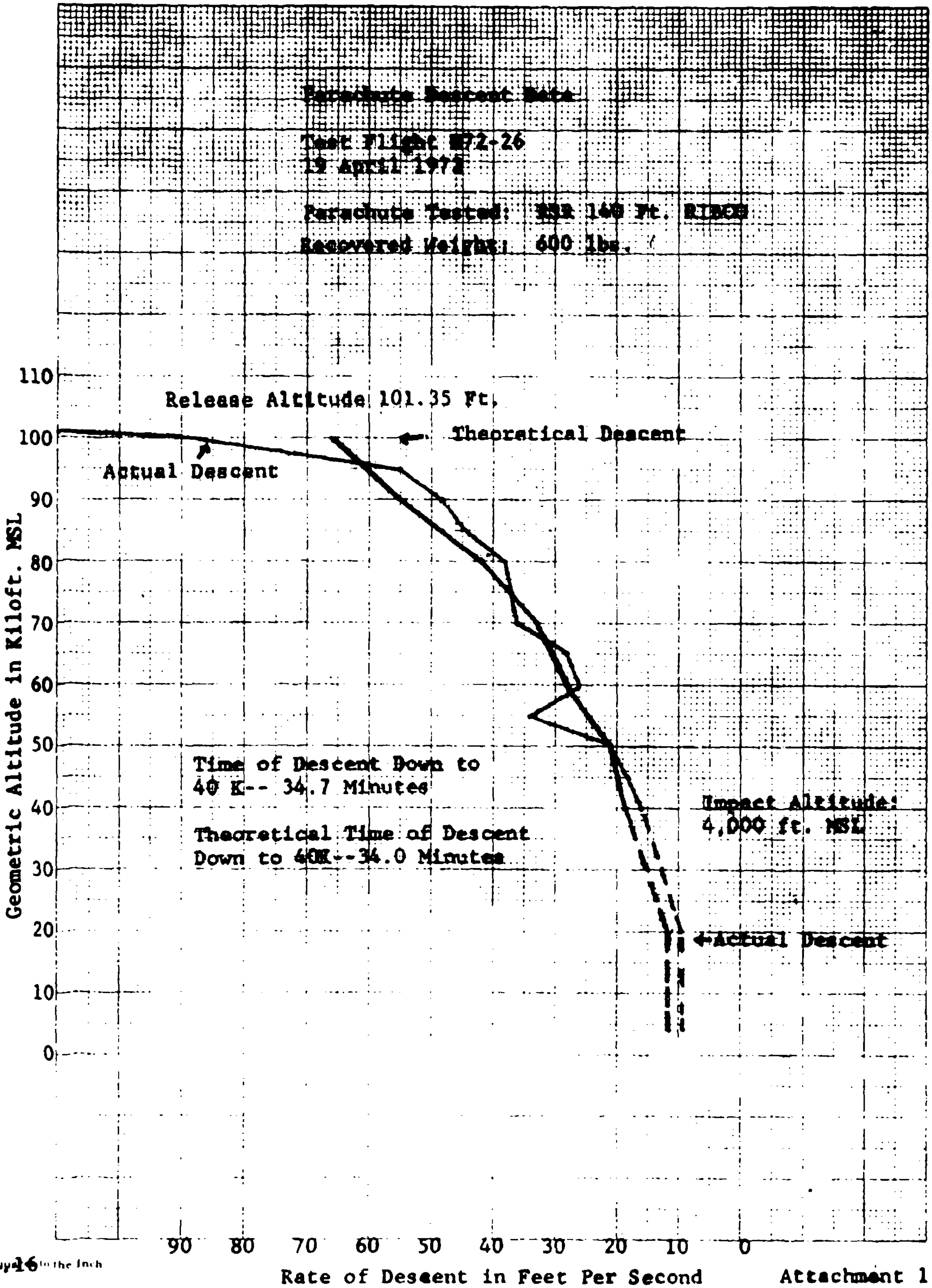
TEST DESCRIPTION AND RESULTS

A 140-foot nominal diameter RSR RIBCO parachute system was tested by Air Force Cambridge Research Laboratories at the Holloman Air Force Base, New Mexico Balloon Flight Facility*. This was a full scale, high altitude test with a 611-pound suspended load. The parachute was rigged according to standard balloon practice with the payload consisting of several instrument packages fastened to a horizontal bar.

To contain the large area of material during balloon launch, in addition to the command-controlled reefing line near the skirt, loops of 25-lb test, 3-cord cotton were tied at 10-ft intervals along the canopy. All of these cotton ties failed during balloon inflation on the runway, and the parachute acted like a spinaker sail during the launch run.

The parachute system performance very nearly approached that desired as optimum for very light loads: Initial snatch force of 2.1 g's at 3.05 seconds after cutdown, an opening shock force of 4.5 g's at 6 seconds after cutdown and a steady state deceleration of approximately 1 g at 10.6 seconds after cutdown. The actual descent time from 100,000 feet to 4,000 feet was 92.3 minutes with theoretical descent time being 90 minutes.

*For complete test description and results see AFCRL Preliminary Report on AFCRL Flight 72-26 Proceedings, Seventh AFCRL Scientific Balloon Symposium.



Attachment 1

CONCLUSION

Based upon the single flight test with the minimum-load requirement, the parachute has substantial improvements over present parachute systems in substantially reduced weight and stability at lower altitudes (20,000 feet to impact). Successful flights with 5000 and 8000 pound payloads can be predicted with confidence in meeting the upper limits of design.

The success of this parachute design provides the user with a single lightweight parachute for use in the wide range of payload weights of 500 lbs to 8000 lbs. It eliminates the need for parachute clustering when recovering payloads in excess of 3000 pounds thereby eliminating problems encountered when using a cluster of parachutes.

Serious consideration should be given to the continued use and development of the RSR RIBCO parachute for balloon recovery. It is the most advanced parachute system design available for recovering sensitive payloads which are not designed to sustain heavy g-load normally experienced during opening shock or ground impact.

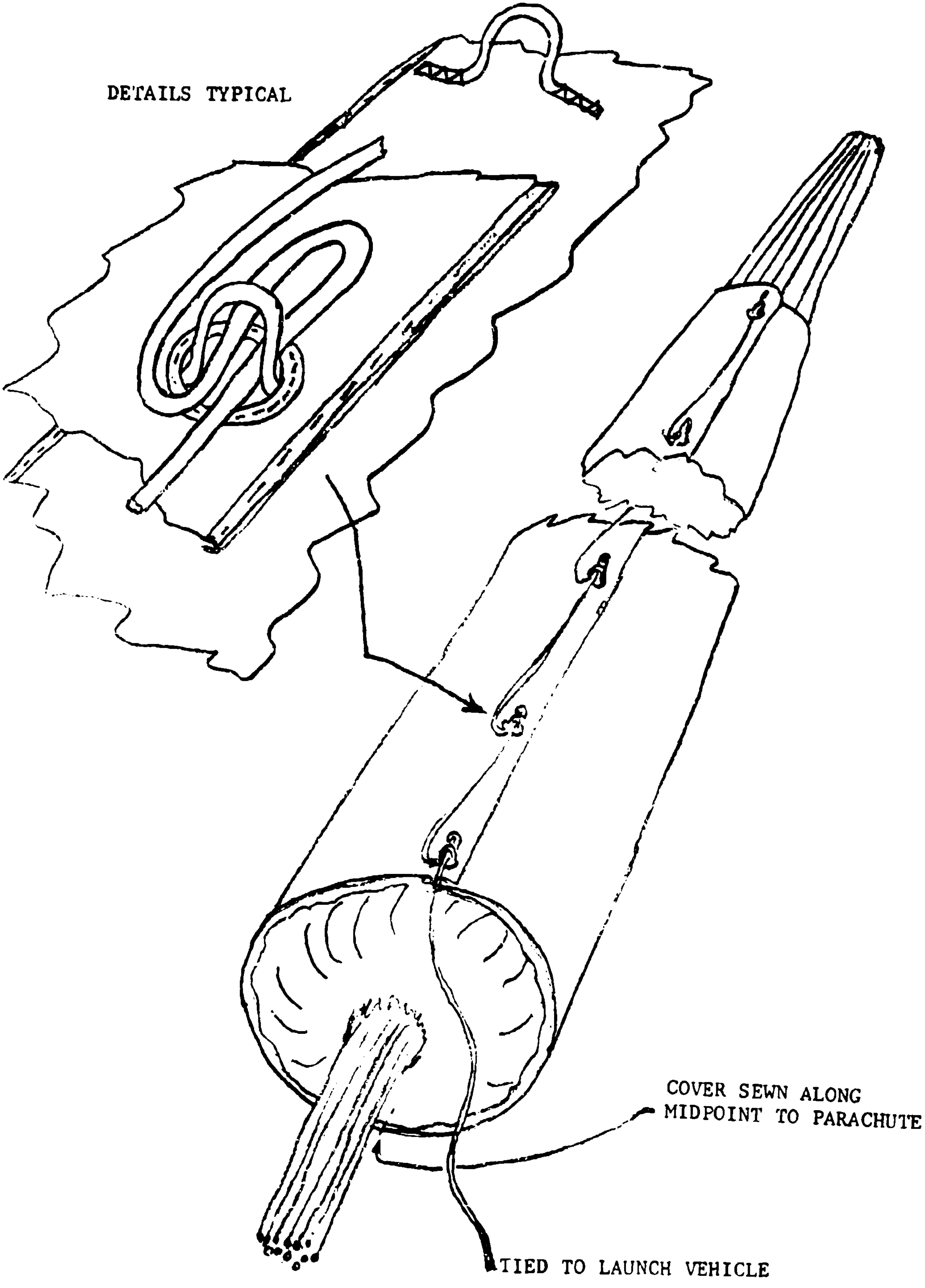
It is further concluded, as reported by AFCRL, that during the preparation for and during balloon launch, the parachute did become difficult to handle in surface winds. Although this was the only problem encountered in using the RIBCO, the canopy can be controlled on the ground by the use of a sleeve arrangement which can be opened by a lanyard when the balloon and payload reach the vertical position at launch. This will also eliminate the need for a skirt retention line and electrically initiated cutters for skirt release.

RECOMMENDATIONS

1. Testing of the RSR RIBCO parachute system be continued through its maximum design payload weight of 8000 pounds to verify design parameters.

2. Recommend that a sleeve arrangement be used to retain and control the parachute canopy during ground operation and launch. Because of design, the canopy cloth has no tension on it during string-out in its prelaunch and flight position. The sleeve method will maintain complete control of the canopy material until released at launch (see Attachment No. 2).

3. Recommend that the riser between the payload and parachute be removed and let the payload be connected directly to the parachute at the lower confluence of the bowline.


DETAILS TYPICAL
COVER SEWN ALONG
MIDPOINT TO PARACHUTE
TIED TO LAUNCH VEHICLE

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